

## APPARATUS AND METHOD FOR SELECTIVELY CONFIGURING A MEMORY DEVICE USING A BI-STABLE RELAY

### TECHNICAL FIELD

5                   The present invention is generally directed to semiconductor memory devices, and in particular to memory devices that may be selectively reconfigured.

### BACKGROUND OF THE INVENTION

                  Semiconductor memory devices constitute an essential part of computer systems  
10   due to the relatively high access speeds obtainable and the generally low cost of such devices. One type of semiconductor memory device that is particularly advantageous is the dynamic random access memory device (DRAM), which utilizes a single transistor and capacitor per memory cell in a memory array structure. The simplicity of this design permits the fabrication of memory devices of relatively high density while providing the lowest cost per bit of any memory  
15   device currently available.

                  Memory devices, such as DRAM, are most commonly identified according their data storage handling capability, generally referred to as the capacity of the device. For example, a 128 megabit DRAM device contains approximately 134 million memory cells, each capable of storing a discrete logic state, or bit, in an array having a predetermined number of rows and  
20   columns. In practical devices, information is stored in address locations that include more than a single bit, so that the 128Mb DRAM may be configured, for example, as a 32 Mb device having 4 bits per address, which is commonly referred to as a 32Mb x 4 device. Alternatively, other configurations are possible, since the 128Mb DRAM may also be configured with 8 or 16 bits per address to form a 16Mb x 8 or an 8Mb x 16 devices, respectively. Other configurations are  
25   also well known, and include DRAM devices having memory arrays arranged in banks of predetermined size.

                  In order to specify an address location for the reading or writing of data to the DRAM, address lines are provided so that the device may accept address inputs. The number of address lines required depends in general on the particular configuration selected for the device.

Referring once again to the exemplary 128 megabit DRAM device, if the device is configured as a 32Mb x 4 device, 25 address lines are required. Correspondingly, if the device is configured as a 16Mb x 8, or a 8Mb x 16 device, the required number of address lines are 24 and 23, respectively. Thus, the number of address lines changes as the memory configuration changes.

- 5 In addition, the number of data input/output lines to the device also depends on the selected configuration. For example, for the x16 configuration, sixteen data input/output lines are required, while the x8 configuration requires only eight. Still fewer are required for the x4 configuration.

During the DRAM manufacturing process, address lines and data input/output  
10 lines are formed on the die to support all of the desired memory configurations. The device is then configured to correspond to a single memory device by various methods. Most commonly, fuses are formed in the die that may be selectively opened to form the desired address lines and data input/output lines. Alternatively, anti-fuses may be formed in the die that form the desired address lines and data input/output lines when a suitable programming voltage is applied. In  
15 either case, the device generally may not be further reconfigured into any other of the possible single memory devices, since the configuration process is irreversible. Consequently, address lines and data input/output lines are often formed on the die that cannot be used in the configured device.

A particular disadvantage associated with the foregoing configuration procedure is  
20 encountered during the testing of the device. Typically, a die is subjected to a number of production test procedures in order to verify that the die is fully operational. During one portion of the test procedure, a predetermined test pattern is written to a selected address, and then subsequently read from the same address. If the address location fails to produce the same pattern that was initially written, an error is noted. If the same pattern is detected, the address  
25 location is verified as functional, and the test is continued until a defective memory address is detected, or alternatively, the test is completed without detecting any defective addresses. When testing is performed on the die, the testing generally proceeds according to a "wide" test format, wherein the size of each address is large. For example, the 128 megabit DRAM device described earlier may have addresses as large as 16 bits, or 32 bits or even larger addresses during wide

testing. Following the completion of the testing, the die is configured into a particular memory device, and is packaged, which generally includes forming connections between various portions of the die and conductors on the package.

Following the packaging procedure, the device is subjected to additional tests that also generally include testing the address locations in the die in the manner described above. Since the device has been configured, however, the ability to test memory addresses by a wide test procedure is no longer possible, since the device has been configured to include addresses of smaller size. Accordingly, a “narrow” test format must be used in post-packaging testing of address locations. Since narrow test procedure must test more address locations than the wide test procedure, more time is required to complete the post-packaging testing using the narrow test.

A packaged memory device may also include more than a single die having suitable interconnections between the individual die that permits the interconnected die to cooperatively form a packaged memory device having a memory capacity that approximates the sum of the memory capacity of the individual die. An example of a multiple die memory device is disclosed in U.S. Patent Application No. 10/355,781, filed January 29, 2003 and entitled MULTIPLE CONFIGURATION MULTIPLE CHIP MEMORY DEVICE AND METHOD, which is commonly assigned and is incorporated by reference herein.

A disadvantage present in the foregoing multiple die memory device is that the post-packaging test procedure may reveal that one or more of the individual die has failed. Since the die have been interconnected, packaged and marked, the entire packaged device is generally discarded, even though other die within the package has been verified to be fully operational.

It is therefore desirable to have an apparatus and a method that permits a memory device to be selectively reconfigured, thus permitting the memory device to be tested according to a wide format test procedure after the memory die has been packaged. Further, and with specific reference to multiple die memory devices, it would be desirable to have a multiple die memory device that permits selective reconfiguration so that the operational die within the packaged device may be used.

## SUMMARY OF THE INVENTION

The present invention is generally directed to a semiconductor memory apparatus having a selectable memory capacity and to methods for testing such devices. In one aspect of the invention, a computer system includes an input, output, and data storage devices, a processor coupled to the input, output and the data storage devices that includes an address bus, a control bus and a data bus to communicate address, control and data signals, a memory device coupled to the processor that includes address, data and command busses, and a configuration circuit interposed between at least one of the address, control and data buses of the processor and the respective address, control and data buses of the memory device to selectively couple lines in the address, control and data busses of the processor to lines in the address, control and data busses of the memory device.

In another aspect, a memory device includes a memory cell array having a plurality of individually addressable memory locations, the memory cell array being coupleable to one or more signal busses of an external device; and a configuration circuit interposed between the memory cell array and the signal busses of the external device to selectively couple portions of the one or more busses to the memory cell array. In a particular aspect, the configuration circuit includes one or more bi-stable relay devices, such as Micro-Electrical-Mechanical System (MEMS) relays.

In still another aspect of the present invention, a selectively configurable memory device includes a first memory die having a first memory capacity, a second memory die having a second memory capacity, and a configuration circuit operable to couple either or both of the first memory die and the second memory die to external circuits to selectively obtain a memory device having a third memory capacity.

In yet still another aspect, a method of testing a memory device having a memory cell array includes subjecting the memory cell array to a first test procedure to determine the operability of the array, the array having a first configuration, packaging the memory device in a device package, subjecting the packaged device to a second test procedure, and configuring the memory cell array to have a second configuration different from the first configuration.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block view of a memory device according to an embodiment of the invention.

5           Figure 2 is a flow diagram that illustrates a method for testing a memory device according to another embodiment of the invention.

Figure 3 is a block diagram of a memory device according to yet another embodiment of the invention.

10           Figure 4 is a block diagram of a computer system according to still another embodiment of the invention.

## DETAILED DESCRIPTION OF THE INVENTION

The present invention is generally directed to semiconductor memory devices, and in particular to semiconductor memory devices that may be selectively reconfigured by Micro-  
15   Electrical-Mechanical Systems (MEMS) devices. In the present context, MEMS refers generally to the integration of mechanical elements and microelectronic devices on a common silicon substrate using currently available or hereinafter developed micro-fabrication technology, such as photolithography, chemical etching processes and the like. Many of the specific details of certain embodiments of the invention are set forth in the following description and in Figures 1-4  
20   to provide a thorough understanding of such embodiments. One skilled in the art will understand, however, that the present invention may be practiced without several of the details described in the following description. Moreover, in the description that follows, it is understood that the figures related to the various embodiments are not to be interpreted as conveying any specific or relative physical dimension. Instead, it is understood that specific or relative  
25   dimensions related to the embodiments, if stated, are not to be considered limiting unless the claims expressly state otherwise.

Figure 1 is a block view of a memory device 10 according to an embodiment of the invention. The memory device 10 includes a memory cell array 12 that includes a predetermined number of memory cells that are interconnected by row and column lines (not

shown). The memory cells are configured to store a logic 0 or a logic 1, and to communicate the logic state along the column lines when a row of memory cells in the array 12 is suitably addressed. The memory cells within the array 12 may therefore include any of a variety of devices capable of storing a logic state, such as the well-known capacitor and transistor combination in a DRAM device. Alternatively, the memory cells may include other bi-polar devices, such as a flip-flop circuit, as used in a static random access memory (SRAM). In either case, the memory cell array 12 may also be configured so that the memory cells of the array 12 are arranged in separate banks of memory cells as is well known in the art.

The memory device 10 also includes an address bus 14 that is coupled to external circuits (not shown) to transfer address signals 16 from the external circuits to the memory device 10. The address signals 16 permit a desired memory location within the memory array 12 to be specified for read and/or write operations. The address bus 14 is also coupled to an address decoder 18 to decode the address signals 16 that are transferred along the address bus 14 so that a decoded memory address may be provided to the array 12. A control bus 20 is similarly coupled to external circuits, and is configured to transfer control signals 22 to the memory device 10 to control various operational aspects of the device 10. The control signals 22 may include, for example, row address strobe (RAS) and column address strobe (CAS) signals to strobe row and column addresses, respectively, and a write enable (WE) signal that enables data to be written to the array 12. Still other control signals may be present to control still other operational aspects of the device 10. For example, a chip select (CS) signal may be used to select a particular memory device for access when more than a single memory device is coupled to the address, control and data signals generated by the external circuits. A clock signal (CLK) may also be present to control the timing of operations within the device 10. The control bus 20 is coupled to a command decoder 24 to decode the command signals 22 that are transferred to the array 12. Finally, a data bus 24 is also coupled to external circuits to transfer data signals 26 from the device 10 to the external circuits, or correspondingly, to transfer the data signals 24 from the external circuits to the device 10. A read/write circuit 28 is also coupled to the bus 24 to transfer the data signals 26 to the array 12.

Still referring to Figure 1, the memory device 10 includes an address configuration circuit 30 coupled to the address bus 14. The address configuration circuit 30 includes at least one bi-stable relay 32 that is coupled to a selected single address line in the bus 14. The bi-stable relay 32 may be comprised of a MEMS bi-stable relay that has a closed state that permits signals transferred along the selected address line to be communicated from the external circuits to the address decoder 18, and an open state, that interrupts the communication of signals communicated along the selected line. The MEMS bi-stable relay is capable of being configured in either the closed state or the open state when the MEMS bi-stable relay is energized by a suitable source, and is further capable of retaining (or latching) the selected state when the source is decoupled from the MEMS bi-stable relay. Accordingly, the address configuration circuit 30 is coupled to a configuration control line 34 that receives a configuration control signal 36 from an external circuit to position the bi-stable relay 32 into either a closed state or an open state, as desired. In a particular embodiment, the bi-stable relay 32 is a MEMS bi-stable relay that is electrostatically actuated by applying a voltage to the configuration control line 34 of approximately about 0.5 volts to approximately about 150 volts. Suitable MEMS bi-stable relay devices are described in detail by Gomm, *et al.*; *In Plane Linear Displacement Bistable Relay*; J. Micromech. Microeng. 12 (2002) at 1-8, and J. Kim, et al.; *Mercury Contact Micromechanical Relays*; Proc. 46<sup>th</sup> Annual Int. Relay Conf.; pp.19-1 to 19-8 (Apr. 1998), which are herein incorporated by reference.

The memory device 10 also includes a data configuration circuit 38 that is coupled to the data bus 24. The circuit 38 similarly includes at least one bi-stable relay 32 that is coupled to a selected single data line in the bus 24. The data configuration circuit 38 is also coupled to the configuration control line 34 so that the configuration control signal 36 may position the bi-stable relay 32 into either a closed state or an open state, which in general, corresponds to selection of address lines in the circuit 30. For example, if a single additional address line is selected by closing a specified bi-stable relay 32 in the circuit 30, the corresponding number of data lines in the circuit 38 will be halved, so that bi-stable relays 32 in the circuit 38 will accordingly be opened.

The memory device 10 may also include a control configuration circuit 40 that is coupled to the control bus 20. The circuit 40 also includes at least one bi-stable relay 32 to couple a selected portion of the control signals 22 to the device 10. For example, if the memory device 10 is a synchronous DRAM (SDRAM), a CLK signal will be required to properly  
 5 synchronize operations within the device 10. In other memory devices, however, the CLK signal may not be required.

In operation, the device 10 may read data stored in the array 12, and provide the data to the external circuits in the following manner. Address signals 16 corresponding to a desired address are provided to the address bus 14. Control signals 22 are also provided to the  
 10 control bus 20, to control the read operation. The address decoder 18 provides a decoded address to the array 12, while the command decoder 24 decodes the control signals on the control bus 20 and transfers the decoded control signals to the array 12. The decoded signals control the array 12 so that the array 12 provides data to the read/write circuit 28. The read/write circuit 28 then provides this data to the data bus 24, which may then be transferred to the external circuits.  
 15 When data is written to the device 10, address signals and control signals are again supplied to the address bus 14 and the control bus 20 by the external circuits. In addition, data signals 26 are provided to the data bus 24 by the external circuits. Once again, the address decoder 18 decodes the address on the address bus 14 and provides the decoded address to the array 12. The read/write circuit 28 then transfers the data from the data bus 24 to the array 12 under the control  
 20 of the decoded control signals received from the command decoder 24.

Although the data configuration circuit 38, the address configuration circuit 30 and the control configuration circuit 40 are shown in Figure 1 as separate units within the memory device 10, it is understood that the foregoing may be incorporated into a single functional unit that selectively couples and decouples address, data and control lines between the  
 25 external circuits and the device 10 when a configuration control signal 36 is applied. It is also understood that the application of the configuration control signal 36 may latch selected bi-stable relay 32 in a closed state, while simultaneously latching other bi-stable relay 32 in an open state. It is further understood that the configuration control signal 36 may be directed to bi-stable relay 32 that are coupled solely to address and data input lines. Alternatively, the configuration control



signal 36 may be directed to bi-stable relays 32 that are coupled solely to address and data input lines. Finally, it is understood that more than a single configuration control signal 36 may be applied to the device 10 on separate lines 34 to individually control the data configuration circuit 38, the address configuration circuit 30 and the control configuration circuit 40 within the memory device 10.

The foregoing embodiment permits address and data lines to be selectively coupled and decoupled to the memory device 10 using one or more bi-stable relays 32. The bi-stable relay 32 advantageously maintain a selected state once actuated, and do not require a connection to a constant energy source in order to maintain the selected state. Accordingly, the foregoing embodiment has significant advantages over other prior art devices. For example, since the selected state of the bi-stable relay is maintained independently of a connection to any energy source, the state is not lost when power is interrupted to the memory device. Furthermore, the selected state of the bi-stable relays 32 is reversible, through the application of a suitable configuration signal to either the address configuration circuit and/or the data configuration circuit. In contrast, various prior art devices, such as fuses and antifuses irreversibly alter the configuration of the memory device 10. This desirable characteristic has various advantages, as will be explained in greater detail in connection with the other embodiments. In particular, the ability to change the configuration of a memory device at various times during manufacturing test procedures, is particularly advantageous, as will be discussed in detail below.

Figure 2 is a flow diagram that illustrates a method 50 for testing the memory device of Figure 1 according to another embodiment of the invention. The memory array 12 of the memory device 10, as shown in Figure 1, is typically subjected to a production test procedure to determine if any of the cells that comprise the array 12 are defective. Typically, a test pattern consisting of a pre-selected combination of 1's and 0's is written to an address within the array 12 and subsequently read from the address and compared to the applied test pattern to determine if any defective cells exist in the address. In general, a memory device is subjected to the foregoing test procedure when in die form, so that a wide format test pattern may be used. In a wide format test, the address width for the device 10 is maintained as large as possible to permit

a relatively large number of memory cells in the array 12 to be tested simultaneously, as shown in step 52. If the cells comprising the array 12 do not test good, or if other defects in the device 10 are detected, the die is either rejected or accepted, as shown in step 54. At this point, a determination regarding alternative configurations for the die may be made, as shown in step 56.

5 For example, if the die has failed the foregoing memory cell pattern test, and other remedies such as selecting a redundant row in the memory device 10 to replace a defective row, as is known in the art, fails to correct the defect, the memory capacity of the device may be degraded by selectively decoupling the defective portion of the array from the device. As a result, the defective memory die may be configured and packaged as a device having a lower memory  
10 capacity, which may be adequate for other alternative applications.

If the die tests good at step 54, or it is determined that the die may be configured into an acceptable and marketable form, the die may proceed to a packaging step 58. During this step, the die is positioned within a suitable package, such as a small thin outline package (TSOP), or another suitable package, and appropriate interconnections between bond pads on the die and  
15 pins on the package are formed. The packaged device may then proceed to a second test procedure at step 60 that again tests the array 12 for defective cells by applying a test pattern to various addresses within the memory array 12. Ordinarily, during the packaging procedure, a device will be configured into its final form (*e.g.* by opening fuses formed on the die, or by programming anti-fuses on the die, or by the manner in which bond wires are attached to the die)  
20 prior to the implementation of the second test procedure, so that the packaged device must be tested according to the device configuration adopted during the packaging step. As described previously, however, the bi-stable relays 32 of the memory device 10 (as shown in Figure 1) may be selectively opened or closed by applying a suitable configuration control signal to the packaged device. The packaged device may therefore be advantageously tested according to the  
25 wide format procedure employed at step 52, thus reducing the time required to test the array 12 in the memory device 10.

Still referring to Figure 2, if defects are detected in the packaged device at step 60, another assessment may be made to determine whether the packaged device is configurable into a marketable form. For example, the memory capacity may be further curtailed for the device,

whereupon it may be segregated and suitably identified as qualified for applications requiring not more than the memory capacity that successfully tested at step 60. If the packaged device successfully passes the tests conducted at step 60, it is then reconfigured into the desired device at step 64 by again applying an appropriate configuration control signal to the packaged device.

5           The foregoing procedure advantageously allows a memory device to be configured during a production test procedure so that the array within the device may be tested in an optimal manner. In particular, the ability to subject a packaged device to a wide format test procedure is viewed as particularly advantageous, since the time required to fully test an array is greatly reduced. Still other advantages are present. For example, devices that cannot  
10           successfully pass the test procedures at steps 52 and 60 may be adapted to conform to other product applications by configuring the device so that it utilizes the memory capacity demonstrated to be good.

          Figure 3 is a block diagram of a memory device 80 according to yet another embodiment of the invention. The memory device 80 includes a pair of memory dies 82  
15           positioned within a package 84. The memory dies 82 are interconnected within the package 84 to cooperatively form a memory device having a memory capacity that is approximately about the sum of the memory capacities of the dies 82. For example, if the dies 82 are 128Mb DRAM dies, the memory capacity of the device 80 is then approximately about 256Mb. The memory device 80 also includes a plurality of address pins 86 positioned on the package 84 to transfer  
20           address signals to the device 80. Similarly, a plurality of data input/output pins 88, and a plurality of control pins 90 are positioned on the package 84 to permit data to be transferred to and from the device 80, and to permit the device 80 to be controlled by external circuits coupled to the device 80. Although a pair of memory dies 82 are shown in Figure 3, it is understood that more than two memory dies may be positioned within the package 84.

25           Still referring to Figure 3, the device 80 includes a configuration circuit 92 that couples the address pins 86, the data input/output pins 88 and the control pins 90 to the memory dies 82. The configuration circuit 92 includes a plurality of bi-stable relays (not shown in Figure 3) that may be selectively opened or closed by transferring a suitable signal from the external circuits to the configuration circuit 92 through one or more configuration pins 94 that are

positioned on the package 84. In a particular embodiment, the bi-stable relays may include bi-stable MEMS devices or any other device that performs a similar function, as described in connection with other embodiments. Although the configuration circuit 92 is shown as a separate unit within the package 84 that is spaced apart from the memory die 82, one skilled in the art will readily understand that the configuration circuit 92 may also be incorporated within the memory die 82.

The foregoing embodiment advantageously allows a packaged device to be salvaged if one of the memory die within the packaged device is rejected during testing. For example, if the packaged device is a 256Mb device comprised of a pair of 128Mb die, when one of the die fails to test good, the packaged device may be configured as a 128Mb device only, and suitably marked as such. The foregoing embodiment has still other advantages. For example, it is well known that costs associated with inventory control are increased as the number of distinct items maintained in the inventory increases. Because the foregoing embodiment allows flexibility in the size of the memory, generally fewer packaged devices would need to be maintained in an inventory, since an ultimate consumer would be able to configure the device according to the consumer's requirement. Further, the flexibility in the memory size in the foregoing embodiment allows a manufacturer to rapidly reconfigure memory devices in order to meet a sudden or unexpected demand for memory devices having a particular configuration. For example, devices having the same structure may be maintained in inventory and selectively configured to fill orders for a 128Mb x 4 memory device, a 64 Mb x 8 memory device, a 32 Mb x 16 memory device, etc..

Figure 4 is a block diagram of a computer system 100 according to still another embodiment of the invention. The computer system 100 includes a memory device 110 that is configured using the bi-stable relay devices as disclosed in connection with the various embodiments of the present invention. The computer system 100 includes a processor 102 that performs various computational functions, such as executing specific software to perform specific calculations. The processor 102 may also perform various control operations associated with the operation of the system 100. The computer system 100 may also include one or more input devices 104, such as a keyboard or a mouse, which are coupled to the processor 102 to

allow an operator of the system 100 to communicate with the system 100. In general, the computer system 100 also includes one or more output devices 106 that are also coupled to the processor 102. The output devices 106 may include a printer, or a visual display device. One or more data storage devices 108 are also typically coupled to the processor 102 to store data, or to  
5 retrieve other data from an external data storage device. For example, the data storage device 108 may include hard and/or floppy disks, tape cassettes, and compact disk read only memories (CD-ROMs). The processor 102 is typically coupled to the memory device 110 through a control bus, a data bus, and an address bus to permit data to be written and/or read from the device 110.

From the foregoing it will be appreciated that, although specific embodiments of  
10 the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention. For example, certain features shown in the context of one embodiment of the invention may be incorporated into other embodiments as well. Accordingly, the invention is not limited by the foregoing description of embodiments except as by the following claims.